UNIVERSITI PUTRA MALAYSIA

PEDO-TRANSFER FUNCTION FOR SATURATED HYDRAULIC CONDUCTIVITY OF PADDY SOILS

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By

AIMRUN WAYAYOK

Thesis Submitted in Fulfilment of the Requirement for the Degree of Master of Science in the Faculty of Engineering
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To my dearest parents

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

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Faculty: Engineering

Soil saturated hydraulic conductivity (K_s) is an important soil physical property, especially for determining infiltration rate, irrigation practice, drainage design, run off, deep percolation, groundwater recharge and in simulating leaching and other agricultural and hydrological processes. Several laboratory and field methods can be used to determine K_s. Unfortunately, laboratory and field determinations are usually time consuming, expensive and labour intensive.

Deep percolation (DP) is the vertical movement of water beyond the root zone to the water table. It is an important component in the calculation of irrigation requirement and irrigation efficiency. Pedo-transfer functions (PTF) serve to translate the basic information found in the soil survey into a form useful for broader applications through empirical regression of functional relationships, such as simulation modelling. PTFs have not been applied to paddy soils in the study area. A lot of field measurements will require high labour input hence high cost.

This study attempts to simplify the determination of K_s. The main objectives of this study were to seek a simplified method for determining K_s values based on PTF and estimate DP losses in paddy field based on the dominant K_s of the soil profile.

Soil samples were collected randomly depending on the soil series within the 2,300 ha Sawah sempadan compartment rice cultivation area. There are five dominant soil series namely, Jawa (*Sulfic Tropaquept*), Sedu (*Typic Sulfaquept*), Sempadan (*Sulfic Tropaquept*), Karang (*Typic Sulfaquept*) and Telok (*Typic Sulfaquept*). Both field work and laboratory work were carried out. The samples were then analysed for the following properties: moisture content in volume basis, bulk density, particle size distribution, organic carbon, pH, electrical conductivity, particle density and moisture content at 33 kPa. The parameters were then used as inputs for developing a K_s model by using SAS (Statistical Analysis System) and SPSS (Statistical Package for Social Science) tools. The K_s values were obtained by using falling head method. Microlysimeter method was adopted to measure the DP loss.

The results of the study showed that the high spatial variability of the saturated hydraulic conductivity in the paddy was high. The best regression model for estimating K_s was based on eight soil properties. Five of the eight parameters are the textural attributes, namely clay (C), medium sand (MS), very fine sand (VFS), fine sand (FS) and silt (Si). Others are bulk density (D_b), organic carbon (OC) and moisture content at 33 kPa ($\theta_{1/3}$). The best model found from this study was $K_s{=}e^{[1\ 285-0\ 967\ (D_b)-8\ 36\times10\text{-}2\ (C)+8\ 55\times10\text{-}2\ (OC)-0\ 134\ (MS)-0\ 943\ (\ln\theta_{1/3})-0\ 349\ (\ln VFS)+0\ 413\ (\ln FS)-2\ 145\ (\ln Si)-0\ 411\ (FS)]}$ ($R^2 = 0.49$).

The results of DP study showed that DP loss could be estimated by knowing the average values of K_s of the three layers (topsoil, hardpan and subsoil). DP loss is best related to K_s by a power function, $DP = 3.29\ K_s^{0.42}$ ($r = 0.60^{**}$). These models still need to be further calibrated or validated with other existing data as the input parameters in order to make it more useful.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

FUNGSI PERALIHAN TANAH UNTUK KEBERKONDUKAN HIDRAUL TEPU BAGI TANAH SAWAH

Oleh

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Keberkondukan hidraul tepu tanah (K_s) adalah sifat fizikal tanah yang penting, terutamanya untuk menentukan kadar resapan, amalan pengairan, rekabentuk sistem saliran, air larian, resapan dalam, imbuhan air bumi, simulasi pelarutresapan dan lain-lain proses pertanian dan hidrologi. Terdapat banyak kaedah makmal dan lapangan yang boleh digunakan untuk menentukan nilai K_s. Walau bagaimanapun, penentuan menggunakan kaedah analisis makmal dan kajian lapangan ini mengambil masa yang lama, kos yang tinggi dan tenaga kerja yang ramai.

Resapan dalam (DP) adalah pergerakan air secara menegak melalui zon akar ke aras air bumi. Ini merupakan komponen penting bagi pengiraan keperluan dan kecekapan pengairan. Fungsi Peralihan Tanah (Pedo-transfer functions-PTF) menyediakan penterjemahan maklumat asas yang di perolehi daripada analisis tanah kepada bentuk yang bersesuaian di dalam aplikasi umum melalui regresi empirikal hubungan berfungsi, seperti pemodelan simulasi. Pada masa ini, PTF belum lagi digunakan di kawasan kajian tanah sawah. Oleh kerana pengambilan banyak data di

kerja intensif dan kos yang tinggi, kajian yang dilakukan akan memudahkan penentuan nilai K_s disamping menjimatkan kos dan tenaga.

Tujuan utama kajian ini ialah untuk memperolehi kaedah ringkas bagi menentukan nilai K_s berasaskan PTF dan menganggar kehilangan DP di sawah melalui nilai K_s yang dominan bagi profil tanah.

Sampel tanah diambil secara rawak dan bergantung kepada siri tanah di antara petak sempadan sawah yang mencakupi kawasan seluas 2300 ha. Di dalam kajian ini, kerja-kerja di lapangan dan kerja-kerja di makmal telah dijalankan. Terdapat lima siri tanah yang dominan iaitu Jawa (*Sulfic Tropaquept*), Sedu (*Typic Sulfaquept*), Sempadan (*Sulfic Tropaquept*), Karang (*Typic Sulfaquept*) dan Telok (*Typic Sulfaquept*). Sampel yang diperolehi dianalisis berdasarkan ciri-ciri berikut iaitu kelembapan tanah berasaskan isipadu, ketumpatan pukal, taburan saiz zarah, karbon organik, pH, keberkondukan elektrik, ketumpatan zarah dan lembapan pada 33 kPa. Kemudiannya, parameter-parameter tersebut digunakan bagi membangunkan model K_s dengan perisian SAS (Statistical Analysis System) dan SPSS (Statistical Package for Social Science). Nilai K_s diperolehi dengan menggunakan kaedah penurunan turus di makmal. Kaedah 'microlysimeter' digunakan bagi menentukan kehilangan DP di lapangan.

Hasil kajian yang diperolehi menunjukkan bahawa keberubahan kawasan adalah tinggi bagi kekonduksian hidraulik tepu. Model regresi yang terbaik bagi menentukan K_s bergantung kepada 8 sifat tanah. Lima daripada lapan parameter adalah taburan saiz zarah, iaitu tanah liat (C), pasir sederhana (MS), pasir sangat halus, pasir halus dan kelodak manakala yang selebihnya adalah ketumpatan pukal, karbon organik dan lembapan pada 33 kPa. Model yang terbaik diperolehi daripada kajian adalah $K_s=e^{[1.285-}$

$^{0.967}$ $_{b}$ $^{1/3}$

= 0.49).

Nilai DP yang diperolehi menunjukkan kehilangan DP boleh dianggarkan dengan memperolehi nilai purata K_s bagi 3 lapisan tanah (tanah atas, tanah keras dan tanah bawah). Kehilangan DP adalah lebih baik dikaitkan dengan K_s melalui fungsi kuasa seperti DP = 3.29 $K_s^{0.42}$

atau disahkan menggunakan data yang sedia ada dari lokasi lain.

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I certify that an Examination committee met on 14^{th} August 2001 to conduct the final examination of Aimrun Wayayok on his Master of Science thesis entitled " Pedo-Transfer Function for Saturated Hydraulic Conductivity of Paddy Soils" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or currently submitted for any other degree at Universiti Putra Malaysia or other institutions.

AIMRUN WAYAYOK

Date: September 11, 2001

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LIST OF ABBREVIATIONS AND SYMBOLS

K_s	Soil saturated hydraulic conductivity (cm s^{-1}).
DP	Deep percolation (mm day^{-1}).
PTF	Pedo-transfer function.
$\partial H/\partial z$	Gradient of the hydraulic head H.
z	Gravitational head.
h_m	Matric pressure head.
h_a	Pneumatic pressure head.
OC	Organic carbon.
θ_v	Volumetric water content.
θ_w	Water content on mass basis.
ε	Porosity of porous material (cm^3 cm^{-3}).
k'	Intrinsic hydraulic conductivity (cm^2).
$r_1, r_2 ... ,r_n$	Mean radius of n pores (cm).
M_d	Particle size distribution median (μm).
GSDI	Grain size distribution index.
GMPS	Geometric mean particle size (mm).
GSD	Geometric standard deviation of the particle size distribution.
$\varnothing_e$	Effective porosity.
ESP	Exchangeable sodium percentage.
R^2	Coefficient of multiple determination.
r	Correlation coefficient.
GMD	Geometric mean diameter (mm).
D_b	Bulk density (g cm^{-3}).
D_p	Particle density (g cm^{-3}).
PSD	Particle size distribution.
S_t	Porosity (%).
OM	Organic matter.
EC	Electrical conductivity (dS m^{-1}).
θ	Moisture content (%).
$\theta_{1/3}$	Moisture content at 33 kPa (%).
DGPS	Differential global positioning system.
ET	Evapotranspiration (mm day^{-1}).
a	Cross sectional area of the standpipe (cm^2).
A	Cross sectional area of the core or brass ring (cm^2).
d	Internal diameter of the standpipe (mm).
D	Internal diameter of the brass ring (mm).
L	Length of the sample in the brass ring (cm).

t	Time required for the water level in the standpipe to fall from H_1 to H_2 (s).
H	Height of water in the standpipe relative to the datum (cm).
V	Volume of the cylindrical core (cm^3).
h	Cylindrical core height (cm).
N_1	Normality of the ferrous solution (N).
N_2	Normality of $K_2Cr_2O_7$ (N).
VFS	Very fine sand
FS	Fine sand
MS	Medium sand
CS	Coarse sand
C	Clay
Si	Silt
S	Sand

CHAPTER I

INTRODUCTION

General

Soil saturated hydraulic conductivity (K_s) is an important soil physical property, especially for determining infiltration rate, irrigation practice, drainage design, run off, groundwater recharge and in simulating leaching and other agricultural and hydrological processes. Several laboratory and field methods can be utilized to determine K_s. Unfortunately, laboratory and field determinations are usually time consuming, expensive and labour intensive.

A study has shown that determining the K_s using Double ring infiltrometer method may require 120 minutes (2 hrs). Rainfall simulator, Guelph permeameter and Guelph infiltrometer may take 125 minutes, 65 minutes and 60 minutes, respectively (Gupta et al., 1993). Some research results indicated that something in the order of 1,300 measurements would have to be made in a 10 ha.-field to accurately measure the K_s to within 10 percent of the mean value (Warrick and Nielsen, 1980). Field soils, on the other hand, exhibit large spatial variabilities in their hydraulic properties, especially their hydraulic conductivity. This variability implies that a large number of field measurements may be required to characterise a given field or area (Jabro, 1992).

Water use in paddy soils losses by deep percolation (DP) where it is the vertical movement of water beyond the root zone or puddle/hardpan soil to the water table. The DP loss is an important component in the calculation of irrigation requirement and irrigation efficiency. Losses by DP experienced will increase water requirement. In drought season, DP losses will affect equitable distribution. Hence knowledge of areas with high DP loss can avoid water distribution to those areas. This will improve the planning of irrigation water supply.

Normally, the determination of soil saturated hydraulic conductivity is based on direct and indirect methods. The direct methods are laboratory and field methods such as Falling head, Auger hole and Guelph permeameter. The indirect method is estimation method such as simulation model. The purpose of the indirect method is to facilitate as good as possible an estimate of Ks based upon its accuracy and efficiency.

When measured hydraulic conductivity is not available, it is a common practice to estimate hydraulic conductivity from routinely measured soil physical and chemical properties, such as particle size distribution, bulk density, organic matter content and so on (Rawls et al., 1982). These estimated functions are often referred to as pedo-transfer functions (PTF) (Bouma, 1992; Bouma and Van Lanen, 1987). Pedo-transfer functions relate different basic soil characteristics or soil properties with one another or land qualities (Bouma, 1989). They serve to translate the basic information found in the soil survey into a form useful for broader applications through empirical regression of functional relationships, such as simulation modelling (Wagenet et al., 1991).

Statement of the Problem

Pedo-transfer functions (PTF) have not been applied to paddy soils in the study area. A lot of field measurements will require high labour input hence high cost. This study will simplify the determination of saturated hydraulic conductivity. If the obtained model or empirical function can be used properly, it can reduce time, cost and labour.

Objectives of the Study

The objectives of this study were to seek a simplified method for determining saturated hydraulic conductivity values and estimate deep percolation losses in paddy field. The specific objectives were:

1. To develop a saturated hydraulic conductivity model based on easily measured soil properties or pedo-transfer function (PTF).
2. To develop a deep percolation losses model based on dominant K_s values of the soil profile.